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Reengineering Deep Space Network Operations

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REENGINEERING DEEP SPACE NETWORK OPERATIONS

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Abstract

The mission set supported by NASA's Deep Space Network (DSN) will increase significantly over the next few years. To accommodate this increase, six new 34 meter antennas are being added to the network. In addition, two excess 34 meter antennas have been acquired from the U. S, Army. At the same time, the DSN budget will be decreasing by half, NASA realized that it would be impossible for the DSN to simultaneously operate and maintain the existing network, increase its level of service, and significantly reduce its budget. To meet these challenges, there needed to be a change in the very manner in which the DSN functions, The DSN is addressing these issues through business process reengineering. This paper addresses the process of reengineering as applied to the DSN as well as the results of that reengineering effort. Changes that are being made to the DSN as a consequence of reengineering are discussed. These changes include modifications to the jobs performed by people in operations and an expanded use of information systems technology.

1. The Case for Change

The DSN is composed of three complexes distributed approximately 120 degrees apart in longitude at Goldstone, California; near Madrid, Spain; and at Canberra, Australia. Central control and coordination is provided by the Network Operations Control Center at JPL in Pasadena, California, When we began our reengineering efforts, each complex consisted of a 70 meter antenna, a 34 meter standard antenna, a 34 meter high efficiency antenna, and a 26 meter antenna. Additionally, the Goldstone complex included a 34 meter beam waveguide (BWG) antenna used for research and development, as well as a 9 meter antenna used for Earth orbiter and Space Shuttle support,

The DSN has served its customers well since its inception. These customers include deep space missions, highly elliptical Earth orbiters (H EOs), and low Earth orbiter (LEO) missions which are not compatible with NASA's Tracking and Data Relay Satellites. Several factors have contributed to a substantial increase in customer service requirements on the DSN in the 1990s. These include an increase of about 50% in the number of deep space missions that will be tracked (from about 10 to about 15) and an even greater increase in Earth orbiters (from about 7 to about 25.) The total effect is an increase in

the number of DSN customers from 16 in 1990 to around 40 in 1999.

In order to accommodate this increased demand, the DSN is increasing its capacity. The planned 1999 DSN configuration is shown in Figure 1. Five ncw 34 meter beam waveguide antennas, 3 at Goldstone and 1 each at Canberra and Madrid, arc being added to the DSN. The first of these antennas began operation this past March at Goldstone. Two additional 34 meter antennas originally built for the U. S. Army near the DSN's Goldstone complex have recently been surplused to the DSN. It should be noted that as wc add these ncw antennas, the 1960's cra 34 meter standard antennas will be decommissioned due to obsolescence. The new 34 meter antennas, along with several smaller, automated tracking stations which arc also under construction, will result in an increase in the number of tracking hours provided each year to DSN customers from about 60,000 in 1990 to about 100,000 in 1999.

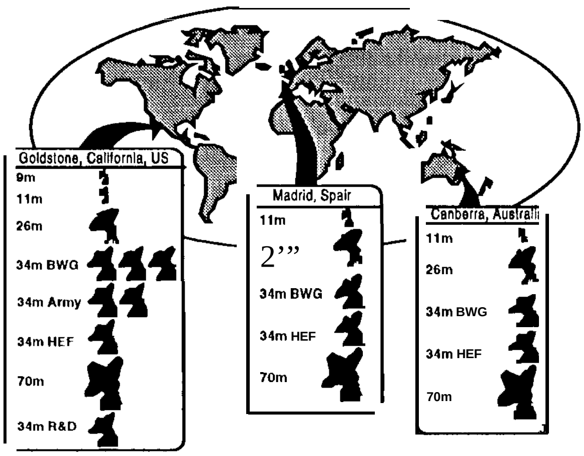

Figure 1.
1994 Antenna configuration of the DSN

NASA. must exhibit ncw capabilities and conduct new. more frequent missions in order to remain vibrant and relevant to the U.S. taxpayer, and continue its mission of expanding human knowledge. As the number of ncw missions is increasing, older missions which arc still producing valuable science will continue to operate. During this same period, NASA's overall budget is expected to decline in real buying power, If the costs of mission operations (including telecommunications) were to remain constant in this period of overall budget reductions, then it stands to reason that ncw developments would be severely constrained. Therefore, the DSN (and other elements of mission operations) must shoulder a greater proportion of the overall budget reductions while simultaneously increasing its capabilities. Doing more with less has become a recurring theme.

Dividing the total 1994 DSN budget (including planning), operations, engineering, and research) by the total number of tracking hours provided leads to a cost pcr tracking hour of about $3,000 (all currency in this paper is in U. S. Dollars.) If the total annual DSN budget were to remain constant through 1999, the cost per tracking hour must decrease to about $1,800 to accommodate the increase in capacity. In reality, the DSN budget will not remain constant over this period, but will decrease. All of this leads to the conclusion that the DSN must become twice as efficient by 1999 as it was in 1994. This degree of progress is not likely to be achieved through the continuous improvement programs already in place, but rather will require a more radical reengineering of the basic processes used in operating the network.

11. Using Reengineering Methodology

Since there would need to be a fundamental change in the way DSN operations functions, wc decided to try using *reengineering*. Reengineering is a technique for creating substantial improvements in performance. The formal definition of reengineering (according to Hammer and Champy[1]) is *the fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical measures of performance.*

Since reengineering was new to JPL, and since it was being used with great success in many American companies at the time, we decided to follow Hammer and Champy's methodology closely. in this way we would achieve two objectives: obtain the required gains in DSN operations efficiency and determine the applicability of reengineering to NASA and the DSN.

Since reengineering is a tool applied to business processes, the first step was to identify the DSN's processes and their interfaces. 'his task was undertaken by the DSN Senior Staff at JPL. Each staff member was sent to a three day training program offered by Hammer and Company, Following this, the staff held a series of meetings over a two month period beginning in February, 1994. The result is the process map shown in Figure 2, Based on the judgment and experience of the staff, the Services Fulfillment process was deemed the most likely to benefit from reengineering and provide the required improvements.

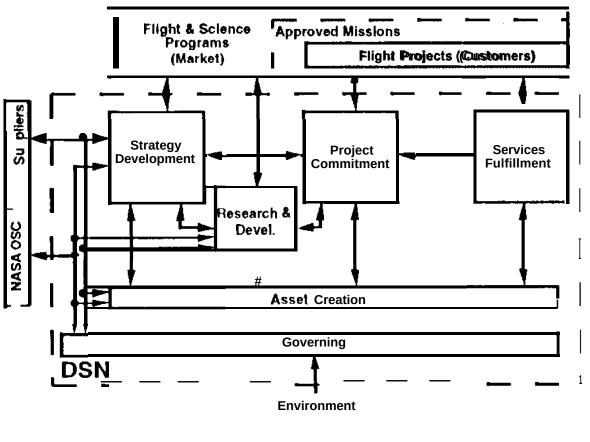

Figure 2.
Process Map for the DSN

Services Fulfillment is the process that contains most of what we think of as DSN operations. There are two principle inputs to the process. One, which comes from the Asset Creation process, are the facilities (assets) required to fulfill services to customers. These assets include antennas, electronics, control systems, and communications lines. The second major input comes from the Project Commitment process. This is a set of contracts with the DSN's customers for tracking support. Services fulfillment's job is to take the contracts and the assets, and deliver DSN services to its customers.

It was decided that Norm Haynes (the JPL director over the DSN) would be the reengineering leader. This person, as outlined in Hammer and Champy's methodology, is the leader who is committed to radical change and has the power to see that the changes actually take place. Ray Amorose (manager of DSN operations) was appointed by Mr. Haynes to be the Process Owner for Services Fulfillment. In this role, Mr. Amorose would be responsible for the functioning of the process before and after the changes that would result from it's reengineering. Mr. Haynes asked Dr. Leslie Deutsch to lead a reeginecring team to redesign the Services Fulfillment process. Dr. Deutsch was, at the time, the manager of the DSN's technology development and science programs.

Dr. Deutsch worked with Mr. Amorose to assemble the reengineering team according to rules set forth by Hammer and Champy. The team was made up of a mix of people from inside and outside the Services Fulfillment Process. The team members were:

Lynne Cooper:
: Process insider with expertise in information systems.

Izeller Cureton-Sneed:
: Process outsider with expertise in data systems.

Leslie Deutsch:
: Process outsider with expertise in technology development and communications systems.

Charles Klose:
: Process insider with expertise in mission operations.

Robert Kwan:
: Process outsider with expertise in communications systems.

John Saxon:
: Process insider with experience in station operations.

Cecelia Seaver:
: Process insider with experience in central operations.

Charles Stelzried:
: Process outsider with expertise in technology development.

Max Wyatt:
: Process insider in operations management

Rod Ziegler:
: Customer (TOPEX/POSEIDON mission manager)

One interesting aspect of the team was the inclusion of a customer. Rod Ziegler is the mission operations manager for the TOPEX/Poseidon mission and has worked on many JPL deep space missions. In addition, James Gavura (station director at NASA/Goddard's White Sands Tracking Station) was a consultant to the team. Mr. Gavura brought outside experience gained in NASA's Space Network (Tracking and Data Relay Satellite System.)

The team members were all trained by Hammer. DSN senior management visibly demonstrated their support for this reengineering activity. The team members were each committed 80% of their time to the reengineering team, which became known simply as the RET. The remaining 20% of their time would be spent back in their home organizations providing feedback on RET activities and soliciting input from the people who ultimately must implement and live with RET findings. NASA and JPL provided dedicated office space and a budget sufficient to complete the RET activities

The RET began work in May, 1995 and continued for ten months. It produced a set of redesigned processes and analyses that will allow the DSN to meet its efficiency improvement goals. The remainder of this paper describes the work of the RET.

III. A Process Map for Deep Space Network Operations

The DSN process map of Figure 2 places Services Fulfillment in context, In order to do any serious work on this process, the RET first identified the major subprocesses of Services Fulfillment. The five major processes in Service Fulfillment and their interfaces are shown in Figure 3, the process map for Services Fulfillment.

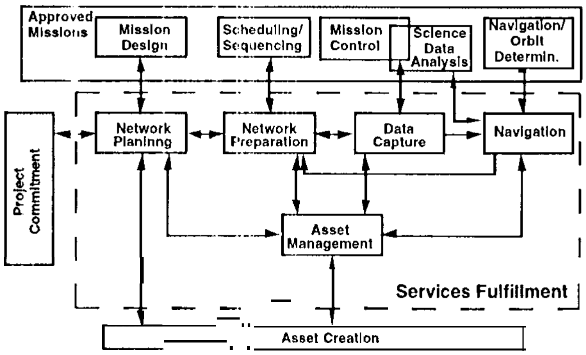

Figure 3.
Process Map for Services Fulfillment

Network Planning takes in the contracts for services with the DSN's customers and develops a strategy for fulfilling them. Operation procedures are developed here as well as any relevant documentation,

Network Preparation is responsible for translating the overall plan produced by Network Planning into detailed plans for individual real time Data Capture *activities*. The RET used the word *activity* to refer to a set of actions that the DSN performs to provide a service to a customer in real time. Activities can include tracking passes with a customer's spacecraft, a ground based science observation using a DSN antenna, or a test with customer hardware or software. Scheduling of the DSN also occurs in the Network Preparation process. Activities are performed in the Data Capture process. This process is generally thought of as real time operations.

Navigation is a process that provides DSN customers with the non-real time service of radio and optical navigation.

Asset Management is the process that accepts facilities from Asset Creation and keeps them running for use by the other processes in Services Fulfillment, Asset Management includes the functions of maintenance and testing.

IV. Selection of Processes to Reengineer

The RET determined the key functions within each of the five major processes in Services Fulfillment and analyzed these to determine which would likely benefit from reengineering.

The DSN's budget and labor utilization was allocated to the processes to determine how resources were consumed by each.

DSN failures for the previous year (as documented in the DSN's failure reporting system) were also allocated among the processes.

A list of complaints from the DSN'S customers was analyzed with respect to the processes. Many of these complaints had already been documented by a process action team that had surveyed most of the DSN's customers. in addition, the RET's customer representative (Rod Zieger) was instrumental in providing additional information.

For each process, the RET brain stormed a set of possible radical changes. These were considered with respect to cost, risk, and schedule.

From this analysis, three subprocesses of Services Fulfillment were selected for reengineering. These subprocesses were selected because the RET determined that (taken together) they had sufficient resources in them to allow for a radical redesign that would meet the DSN'S efficiency goal. In addition, the RET determined that theses subprocesses were in need of redesign and that an effort in these areas could be successful in a short time.

The first selected process, Data Capture, is the entire major process shown in Figure 3

The second, Activity Planning, is a subprocess of Network Preparation. Activity Planing is the process of generating and disseminating all the support data required to support a real time activity. This data includes DSN Predicts (data used to configure and monitor the performance of the DSN assets) and Sequences of Events (the lists of instructions that define the services to be performed during the activity.)

The third was Scheduling. Later, the RET recommended that scheduling be redesigned out side of the RET's work since most of the money spent on scheduling is spent by the DSN'S customers - not the DSN. There is actually little to be gained within the DSN by reengineering scheduling.

V. Data Capture Reengineering

The RET began their reengineering of Data Capture by developing its process map. Since this is a description of the basic value-added activities that must be performed to accomplish Data Capture, this map represents both the old system and the future, reengineered system. The process map for Data Capture is shown in Figure 4.

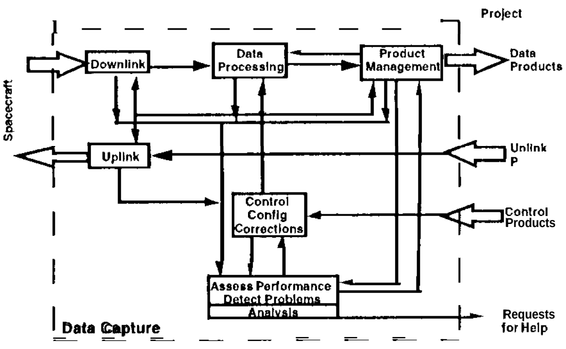

Figure 4.
Data Capture Process Map

The Data Capture process has Uplink and Downlink processes that perform all of the standard services required in the communications function of the DSN. The Data Processing process provides additional services by transforming the received downlink data into forms that have a greater value to the customer. Functions in Data Processing include decoding, decompression, and restoring the order of the received data.

Product Management provides for the maintenance of customer-oriented data bases (a service that is provided for some customers of the DSN.)

The remaining processes provide the control function that allows the Data Capture process to perform its job and interface with its customers.

The RET then set about understanding the present implementation of Data Capture in the DSN. A high level view of that implementation is shown in Figure 5.

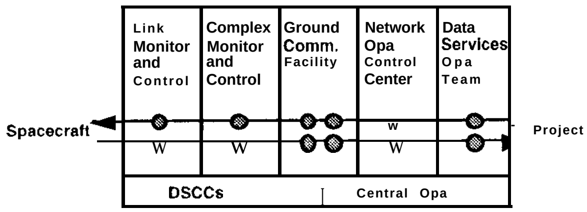

Figure 5.
Present Data Capture System

The little circles represent control points in the system. The important point to notice is that the current system is divided into a series of separate facilities. Each of these facilities has its own people, tools, and procedures, Each one has to work in order for Data Capture to succeed in delivering customer services.

Historically, it was beneficial to build Data Capture in this way. When the DSN was new, there were many complex engineering challenges to overcome. Dividing the problem up into simpler tasks resulted in a manageable set of goals to accomplish.

There are, however, several problems with this facilities- oriented approach. First, there is a tendency to duplicate functions in each facility. Examples of this duplication include the customer interface function, report generation, and certain kinds of tool development.

A second problem is that each of the interfaces between these facilities must be managed carefully to reduce errors. This is particularly difficult as adjacent facilities on the diagram can be in distinct management organizations.

The RET decided to reengineer Data Capture by reducing the number of facilities to just two and redefining all the jobs in the system. The result is shown (at a high level) in Figure 6.

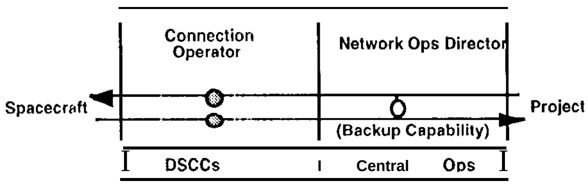

Figure 6.
Reengineered Data Capture System

In the new Data Capture system, a single person (called a Connection Operator) will be responsible for the end-to-end process during any real time activity. Depending on the maturity of the tools that that person has, there can be a team of people reporting to a Connection Operator for an activity, or a single Connection Operator can control multiple activities at a time. During any activity, the Connection Operator provides the primary interface with the customer. In some sense, the Connection Operator can be thought of as working for the customer.

At some central location, a single person, the Network Operations Director (NOD) will be responsible for the execution of Data Capture for all customers. The NOD will have similar tools to those used be the Connection Operators and can assist with the handling of exceptions that may occur. Exception Handlers will work for the NOD and will provide additional expertise to assist the Connect ion Operators when trouble arises, The NOD is responsible to the process owner of Dat a Capt ure.

In order to achieve the efficiency goals outlined in Section 1, additional tools and infrastructure must be provided for both the Connection Operator and the NOD. These include a modern system for monitor and control that will give the Connection Operators visibility into the end-to-end data path and a global wide area network (WAN) so that control information and customer data can be managed efficiently around the world.

The RET analyzed each of the types of jobs required in the present and reengineered Data Capture systems. The number of distinct operator positions required in the present system is about 150 while the new system will require only about 60. In both cases, there is an overhead required for management and training of the operations staff and to allow for absences.

The rate at which DSN operating costs are reduced depends on the rate at which the required new tools are implemented. We expect these tools to be available for DSN operational use within three years. The RET has est imated the cost of the new tools to be about $12M. Taking this schedule and cost estimate into consideration, the RET believes that an annual cost reduction in Data Capture of about $1 OM is achievable beginning in 1999. NASA is committed to achieving these cost savings since they have already been assumed in NASA budget planning

VI. Activity Plan Reengineering

The RET began its reengineering of Activity Planning in the same way. The process map for Activity Planning appears in Figure 7. There are two major pieces to the process. The first is shown on the top half of the Figure and represents the functions that produce predicts information.

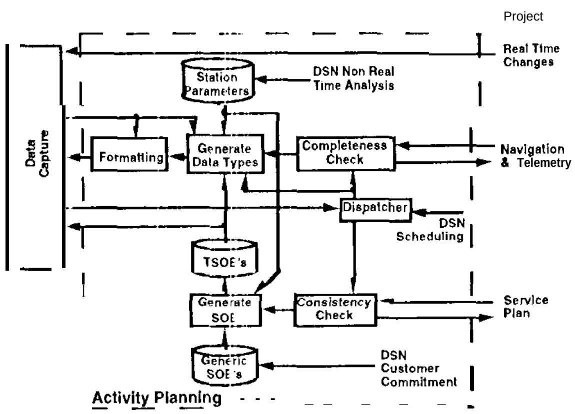

Figure 7.
Activity Planning Process Map

The second is shown at the bottom of the Figure and represents the functions required to define the services that will be performed during and activity.

The present Activity Plan system generates predicts well in advance of an activity in a computational batch mode. Because of this, multiple sets of predicts are generated to cover probable contingencies (such as moving a customer's activity to a different antenna, or slipping it in time.) In addition, there are three principle methods of transmitting the predicts to the stations, resulting in confusion during activities. All of this results in a labor-intensive process.

The reengineered Activity Plan system will provide the Connection Operator with the tools to generate predicts on the fly, based on the most current raw data (which will reside in a global data management system on the WAN.) in this way, only the customer-dependent data need to captured in advance. The actual predicts can be calculated after a definitive station configuration has been assigned. Also, it will be easier to regenerate predicts in case of major contingencies (such as an antenna failure.)

The present Activity Plan system takes Sequence of Event (SOE) data from the customer. SOE data consist of actual instructions to DSN equipment. SOEs are very configuration-dependent. If the customer's activity must be moved to another antenna, or if the customer desires to change services during an activity, the SOE becomes useless.

in the reengineered Activity Planning system, customers will provide a Service Plan instead of SOEs. The Service Plan will state the desired services (i.e. one-way telemetry, Doppler, command, ,,.) and dependencies (i.e. only perform a command after a signal is detected from the spacecraft) rather than equipment-specific commands. The Service Plan will be automatically translated at the DSN stations into appropriate commands for the configured equipment. In this way, the customer will not have to be concerned with DSN equipment. Also, the Connection Operator will have considerably more flexibility to apply equipment during an activity.

The RET estimated that the reengineered Activity Plan process will result in a savings of just under $1M annually starting in 1998. The new tools required will cost about $3.7M. Most of this cost is for the knowledge engineering required to implement the Service Plan system.

VII. Demonstrations

in keeping with the reengineering methodology as promoted by Hammer and Champy, the RET set up two laboratory demonstrations of key concepts in the new process designs. By doing this, the RET was able to recognize shortcomings and correct them before a full implementation had begun.

The first demonstration was a subset of the Connection Operator concept. A single customer, Voyager 2, was chosen. During selected Voyager 2 activities, the link operator was given the additional responsibility of interfacing with the Voyager project. This was accomplished under varying circumstances and with varying levels of support from central operations. As a result of this demonstration, the transition plan for Connection Operations was honed and is now in place,

A second demonstration involved the concept of the Service Plan. Since the operational DSN stations did not have the necessary control systems, this demonstration was carried out at the 34 meter BWG research and development antenna (designated Deep Space Station 13, orDSS13) at Goldstone. DSS13 is equipped with a control system that is serving as an engineering model for the next generation DSN control systems. It has the ability to execute complex actions by using Operator Assistant technology[2].

Again, Voyager 2 was chosen for the demonstration. Since DSS13 is not an operational station, it was used only in addition to a second (operational) antenna at Goldstone. At no time was required DSN support for Voyager 2 jeopardized.

The Voyager 2 SOE was converted, automatically, to a service plan. If the service plan indicated that the Voyager project had requested one-way telemetry (a service that DSS 13 can provide) then the service plan was sent to DSS13. DSS13 then performed the activity autonomously by converting the service plan into DSS13-specific parameters. These parameters were inserted into a Temporal Dependency Network[3] (TDN.) A TDN is a formalized representation of an operation process including dependencies between actions and associated contingencies. Once a process has been described by a TDN, it can be executed autonomously. In this case, the TDN was executed at DSS 13 by the Operator Assistant, a software control system designed for this purpose.

The results of the DSS 13 demonstration have been used to further define the concept of a service plan and to help develop requirements on new control systems for the DSN.

VIII. Quick Hits

There are savings that will be accomplished even before the new tools are in the field. These are the results of *quick hits,* fast changes in the way the work is performed that do not involve substantial investment in new facilities.

There are four quick hits that we are currently putting into practice. The first involves moving toward the concept of the Connection Operator. We have already begun changing the role of the Link Operator (the person who monitors and controls station front end equipment) to include interfacing with the customer. As this progresses, we can reduce the number of operators at our central facility that perform that role.

The second quick hit involves making a modest investment in our **26** meter antennas (used primarily for HEO support) to reduce the need for dedicated operators for their specialized front end equipment.

The third quick hit involves the consolidation of many of our central operations functions into a single floor of a building. This will facilitate the cross training of the various operation teams and result in a smooth transition to a single, smaller central operations facility,

The final quick hit involves a restructuring of the operation documentation process. Although this wasn't one of the processes addressed by the RET, it was identified as having potential and given to our operations contractor (AlliedSignal) as a challenge.

IX. Conclusions

The DSN has begun implementation of the RET team recommendations. New tools will be available by 1998. The cross-over point for achieving savings (after investment costs in tools and training are considered) will occur in 1999. These changes will permit the DSN to meet its efficiency goals, cutting the cost per tracking hour in half by 1999, as outlined earlier in this paper.

We have found our reengineering experience to be not only beneficial for improving network operations, but essential to the continued viability of the DSN.

As with any management approach, we would encourage application of reengineering principles when it is appropriate - i.e. when radical improvements are necessary - but realize that this tool may not be appropriate in all instances.

Our own successful experience with reengineering has lead to the adoption of this technique within JPL for redesign of some of its key business practices.

References

1. M. Hammer and J. Champy, Reengineering the Corporation, HarperBusiness, New York, NY, 1993

2. L. Lee & L. Cooper, "Link Monitor & Control Operator Assistant: A Prototype

Demonstrating Semi-automated Monitor & Control," TDA Progress Report 42-115, July-September 1993, Jet Propulsion Laboratory, Pasadena, CA, pp. 124 - 134, November 15, 1993.

3. K. Fayyad & L. Cooper, "Representing Operations Procedure; Using Temporal Dependency Net works," SpaceOps '92, November 17-19, 1992, Pasadena, CA.

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